BIODEGRADABLE POLYMER COMPOSITIONS, METHODS FOR MAKING SAME AND ARTICLES THEREFROM

CROSS-REFERENCE TO RELATED APPLICATION(S)

The present application is a Continuation-In-Part of Application Serial No. 09/289,702, filed April 12, 1999.

GOVERNMENT RIGHTS IN INVENTION

The present invention was made with government support under Grant Agreement No. 59-3K95-3-126 awarded by the United States Department of Agriculture, Agricultural Research Services. The government has certain rights in this invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to polymer compositions and, more particularly, to biodegradable polymer compositions, methods for making same and articles therefrom.

2. Description of the Related Art

Starches and modified starches have been the focus of considerable research interest in attempts to use these as fillers in order to decrease polymer costs and to use polymers that are biodegradable. Several recent examples, U.S. Patent No. 5,384,187, issued January 24, 1995, inventors Uemura et al., U.S. Patent No. 5,391,423, issued February 21, 1995, inventors Wnuk

et al., and U.S. Patent No. 5,412,005, issued May 2, 1995, inventors Bastioli et al., all represent domestic and foreign based attempts to achieve biodegradable polymer compositions in which natural polymers such as starches have been added to hydroxy-functional polymers.

Recent biodegradable polymer compositions have included a starch or a modified starch and a hydroxy-functional polymer. An example of such a biodegradable polymer composition is disclosed in U.S. Patent No. 5,852,078, issued December 22, 1998, to inventors Willett et al. This biodegradable polymer composition includes the use of granular starch and thermoplastic poly(hydroxy ester ethers)(PHEE) made with various difunctional acids such as adipic acid. However, uses of this composition may be extremely limited due to the low glass transition temperature of the PHEE made with adipic. Most articles formed from this composition easily softened and lost their shape at high temperatures of up to and more than 100°C.

Further, it is known to mix starch with a thermoplastic polyester such as poly(lactic acid)(PLA). It is also known that such a mixture is immiscible and any resultant article formed is brittle with poor material properties. Therefore, there is a need in the art to provide polymer compositions with hydroxy-functional polymers and thermoplastic polyesters that are useful in the manufacture of biodegradable plastics, but which are easily prepared and processed into articles that keep their shape at high temperatures.

SUMMARY OF THE INVENTION

Accordingly, the present invention is polymer composition. The polymer composition includes a first component being a hydroxy-functional polymer, a second component being a natural polymer and a third component being a thermoplastic polyester. The first component, second component and third component are combined to form the polymer composition.

Also, the present invention is an article. The article includes a first component being a hydroxy-functional polymer, a second component being a natural polymer and a third component being a thermoplastic polyester. The first component, second component and third component are combined to form a polymer composition which is processed into the article.

Further, the present invention is a method of making a polymer composition. The method includes the steps of providing a first component being a hydroxy-functional polymer, providing a second component being a natural polymer and providing a third component being a thermoplastic polyester. The method includes the steps of combining the components to form a polymer composition.

The polymer compositions of the present invention are biodegradable and useful in various processes such as molding, extruding and casting to form molded articles and extruded sheets. The hydroxy-functional polymer may be as described by U.S. Patent No. 5,171,820, issued December 15, 1992, to inventors Mang et al., U.S. Patent No. 5,496,910, issued March 5, 1996, to

inventors Mang et al., and PCT application published as International Publication No. WO 97/23564, on July 3, 1997, to inventors Mang et al. Natural polymers for mixture with the hydroxy-functional polymers include polysaccharides, modified polysaccharides, naturally-occurring fibers, and particulate fillers. Particularly preferred as the natural polymer are starches. The thermoplastic polyesters for mixture with the natural polymers and hydroxy-functional polymers include poly(lactic acid)(PLA), poly(butylene succinate adipate) and poly(butylene succinate) copolyesters such as Bionolle™, cellulose acetate, polycaprolactone and polyhydroxy(butyrate-co-valerate)(PHBV).

One advantage of the present invention is that new polymer compositions are provided which are useful in the manufacture of biodegradable plastics. Another advantage of the present invention is that a method is provided of making such polymer compositions. Yet another advantage of the present invention is that articles are easily prepared from such polymer compositions that keep their shape at high temperatures of up to and more than 100°C. Still another advantage of the present invention is that the polymer compositions contain starch and a hydroxy-functional polymer such as poly(hydroxy ester ether)(PHEE) and a thermoplastic polyester such as poly(lactic acid)(PLA). A further another advantage of the present invention is that the method compounds the composition in at least one compounding step. Yet a further advantage of the present invention is that

the compounded composition is pelletized for further processing in various processes such as injection molding. Still a further advantage of the present invention is that the polymer compositions are biodegradable and allow molded items to be formed such as planter pots, disposable razors, cutlery, pen casings, etc., with little concern of softening at high temperatures of up to and more than 100°C.

Other features and advantages of the present invention will be readily appreciated as the same becomes better understood after reading the subsequent description, examples and the appended claims.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Broadly, the present invention is a polymer composition comprising three main components: the first component is a hydroxy-functional polymer, more particularly, a hydroxy-functional polyester having a repeating structure as will hereinafter be described. The hydroxy-functional polymer may be, for example, a thermoplastic poly(hydroxy ester ether)(PHEE). The second component is a natural polymer. The natural polymer may be, for example, a polysaccharide, a modified polysaccharide, or a naturally occurring fiber or particulate filler, but preferably is starch or a modified starch. The third component is a thermoplastic polyester. The thermoplastic polyester may be, for example, a thermoplastic poly(lactic acid)(PLA).

While the amount of the hydroxy-functional polymer selected for use depends on a variety of factors, including the specific polymer employed and the desired end uses of the composition, in general hydroxy-functional polymers can be present in an amount of from 1 to 99 wt.%, preferably from 1 to 95 wt.%, and most preferably from 10 to 90 wt.%, based on the total weight of the composition. Preferably, the thermoplastic polyester is a poly(lactic acid)(PLA), present in amounts of about equal to or greater than the amount of the hydroxy-functional polymer used in the formulation of the composition.

Natural polymers contemplated for use include biodegradable organic fillers, such as cellulose and other fibers and the like, which are well known. Naturally occurring fibers or particulate fillers which can be employed in the practice of the present invention for preparing the composition are, for example, wood flour, wood pulp, wood fibers, cotton, flax, hemp, or ramie fibers, rice or wheat straw, chitin, chitosan, cellulose materials derived from agricultural products, nut shell flour, corn cob flour, and mixtures thereof. Polysaccharides which can be employed in the practice of the present invention for preparing the composition are the different starches, celluloses, hemicelluloses, gums, pectins, and pullulans. Polysaccharides are known and are described, for example, in *Encyclopedia of Polymer Science and Technology*, 2nd edition, 1987.

Modified polysaccharides which can be employed in the practice of the present invention for preparing the composition

are the esters and ethers of polysaccharides, such as, for example, cellulose ethers and cellulose esters, or starch esters and starch ethers. Modified polysaccharides are known and are described, for example, in *Encyclopedia of Polymer Science and Technology*, 2nd edition, 1987.

The natural polymer is in a granular form (hereinafter referred to as the "granular embodiment"). When practicing the granule embodiment of the present invention, the granules of natural polymer preferably will have a particle size of less than about 100 μm, and more preferably have a particle size of up to about 50 μm and a water content of less than about 15 wt.%, more preferably less than about 10 or 11 wt.%. In the granule embodiment, the three main components may be admixed in varying amounts. The natural polymer may be present in a trace amount or in greater amounts up to about 74 wt.%.

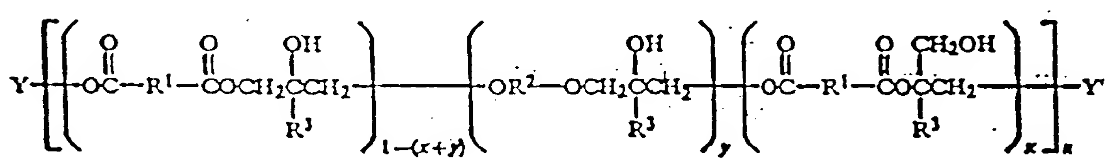
Suitable Hydroxy-Functional Polymers

The preparation and structures for hydroxy-functional polymers, such as hydroxy-functional polyesters, suitable in practicing the present invention may be as described by U.S. Patent No. 5,171,820, issued December 15, 1992, to inventors Mang et al., and U.S. Patent No. 5,496,910, issued March 5, 1996, to inventors Mang et al., the disclosures of which are hereby incorporated in their entireties by reference. Such useful hydroxy-functional polyesters for the present invention may be prepared from base-catalyzed nucleophilic addition of suitable

acids to epoxies, which reaction generates both an ester linkage and a pendent hydroxyl group. Transesterification and cross linking reactions are eliminated through use of quaternary ammonium halide salts as initiators for the reaction of diacids with diglycidyl ethers, providing convenient preparation of high molecular weight, thermoplastic, hydroxy-functional polyesters in ether solvents at temperatures from 80°C-160°C. Data provided by the Dow Chemical Company (manufacturer of hydroxy-functional polyesters such as described by U.S. Patents Nos. 5,171,820 and 5,496,910) indicates the biodegradable nature of these polymers through the ability of various soil bacteria (such as *Pseudomonas putida*) to use the synthetic polymers as a substrate for cell culture growth.

Representative structures for suitable hydroxy-functional polyesters in practicing the present invention are represented by Formula A (where n provides a sufficient molecular weight, such as for example a m.w. of about 50,000-100,000. Higher molecular weights are preferred due to higher strength.

FORMULA A

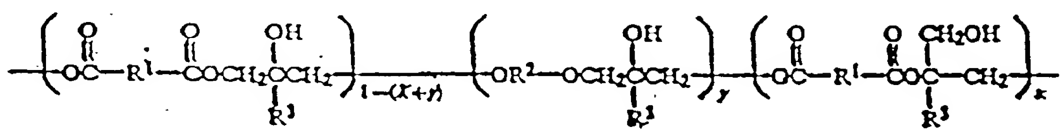


In Formula A each of R^1 and R^2 is individually a divalent organic moiety which is predominately hydrocarbon, each R^3 is individually a hydrogen or lower alkyl, y is a fraction from 0 to 0.5 and x is a fraction from about 0.05 to about 0.4.

Typically Y is hydrogen or glycidyl and Y′ is glycidyl arylene ether, glycidyl alkyene ester, glycidyl alkylene ether or glycidyl arylene ester.

Thus, suitable polyesters have repeating units represented by Formula B (where each of R^1, R^2, R^3, x and y are as defined above).

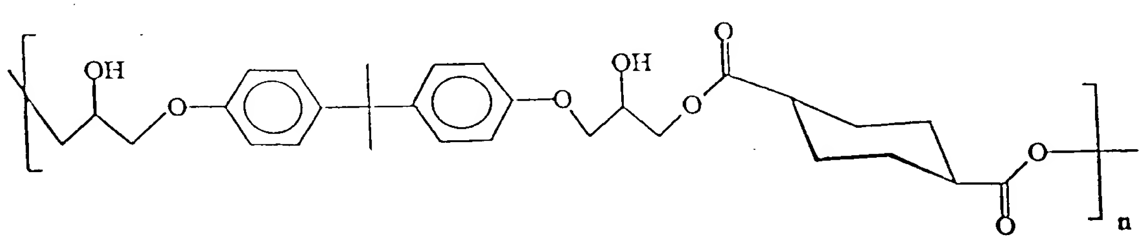
FORMULA B



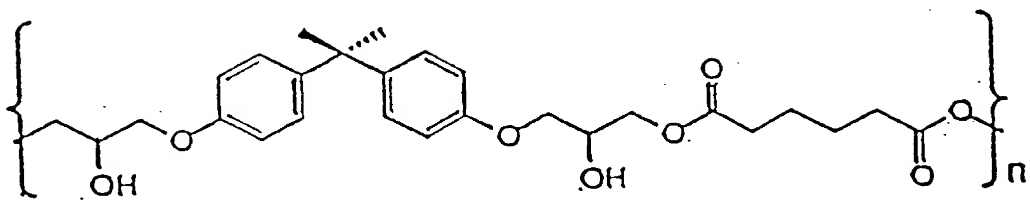
Such polyesters may be prepared from diglycidyl esters of an aliphatic diacid such as adipic due to the ready availability and reasonable price for adipic acid as a source of reactant. Other particularly preferred polyesters may be prepared from dihydric phenols, such as hydroquinone.

Four particularly preferred hydroxy-functional polyesters, used extensively to illustrate (but not to limit) the present invention, are sometimes hereinafter designated "BIS CHD," "BIS adipic," "HQ DDCA" and "BIS DDCA." These polymers will include some repeating unit structures, where the repeating units are illustrated respectively by Formulas C-F.

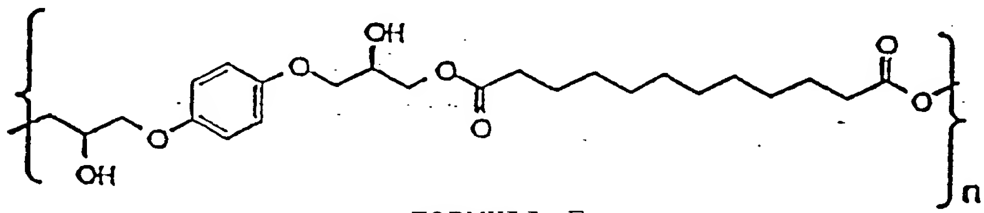
FORMULA C



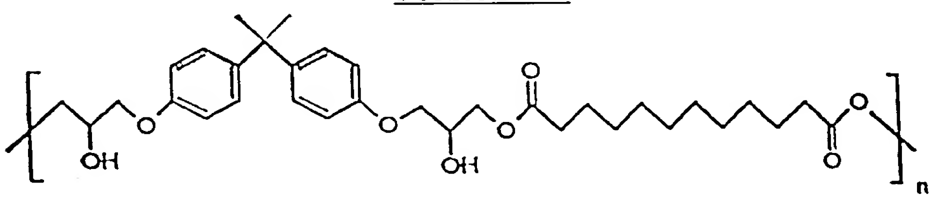
FORMULA D



FORMULA E



FORMULA F



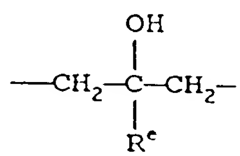
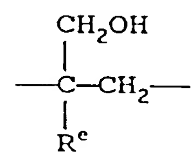
In Formulas C-F, "n" preferably is as earlier described.

Other suitable hydroxy-functional polymers for practicing the present invention are described by Formula I in PCT application published as International Publication No. WO 97/23564, on July 3, 1997, to inventors Mang et al., the disclosure of which is hereby incorporated in its entirety by reference. The below illustrated repeating structure described by U.S. Patent No. 5,496,910, issued March 5, 1996, to inventors Mang et al., incorporated herein by reference and designated here as Formula I is believed to encompass Formula B.

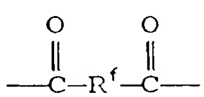
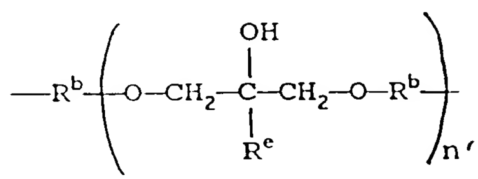
Thus, the Formula I polymers have repeating units represented by the formula:

$$-\!\left(\!-\mathrm{O}\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-\mathrm{R}^{a}-\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{OR}^{c}\mathrm{OR}^{d}\mathrm{O}-\mathrm{R}^{c}-\!\right)\!- \qquad \mathrm{I};$$

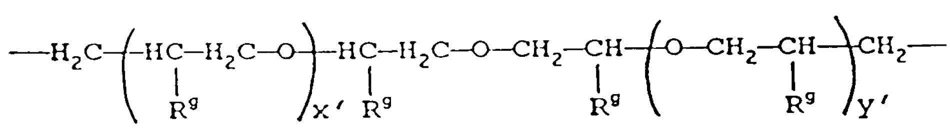
wherein R^a individually represents a divalent organic moiety which is predominately hydrocarbylene (where the term "hydrocarbylene" means a divalent aliphatic hydrocarbon moiety, such as alkylene, alkenylene or cycloalkylene having 2 to 20 carbons and optionally containing a heteroatomic group, such as oxygen, sulfur, amino, sulfonyl, carboxyl, carbonyl or sulfoxyl, in the chain or pendant thereto) or a combination of different organic moieties which are predominantly hydrocarbylene; R^c is

 or  ; and

R^d is

 or  ;

wherein R^b is a divalent organic moiety which is predominantly hydrocarbylene or



R^e is hydrogen or lower alkyl, such as methyl, ethyl, butyl and propyl, more preferably hydrogen, R^f is independently an organic moiety which is predominantly hydrocarbylene, R^g is independently hydrogen or methyl, n' is an integer from about 0

to about 100, and x' and y' are independently integers from 0 to 100.

Representative divalent organic moieties useful as R^a, R^b, and R^f include alkylene, cycloalkylene, alkylenearylene, poly(alkyleneoxyalkylene), alkylenethioalkylene, alkylenesulfonylalkylene, alkylene substituted with at least one hydroxyl group, cycloalkylene substituted with at least one hydroxyl group, alkylenearylene substituted with at least one hydroxyl group, poly(alkyleneoxyalkylene) substituted with at least one hydroxyl group, alkylenethioalkylene substituted with at least one hydroxyl group, alkylenesulfonylalkylene substituted with at least one hydroxyl group, arylene, dialkylenearylene, diaryleneketone, diarylenesulfone, diarylene oxide, and diarylene sulfide.

In the more preferred hydroxy-functional polyethers, R^a, R^b and R^f are independently methylene, ethylene, propylene, butylene, pentamethylene, hexamethylene, heptamethylene, octamethylene, nonamethylene, decamethylene, dodecamethylene, 1,4-cyclohexylene, 1,3-cyclohexylene, or 1,2-cyclohexylene optionally substituted with at least one hydroxyl group, p-phenylene, m-phenylene, or 2,6-naphthalene, diphenyleneisopropylidene, sulfonyldiphenylene, carbonyldiphenylene, oxydiphenylene, or 9,9-fluorenediphenylene and n' is from 0 to 10.

The polymers represented by Formula I may be prepared by reacting diglycidyl esters or aliphatic or aromatic diacids such

as diglycidyl terephthalate, or diglycidyl ethers of dihydric phenols or alcohols with aliphatic or aromatic diacids such as adipic or terephthalic acid. Thus, suitable polymers for the present invention can be prepared by reacting a hydroxy-functional aliphatic diacid, optionally in the presence of another diacid, with a diglycidyl ether or diglycidyl ester or a mixture of diglycidyl ethers or diglycidyl esters at conditions sufficient to cause the acid moieties to react with the epoxy moieties to form a polymer backbone having ester linkages, as described in U.S. Patent No. 5,171,820.

<u>Natural Polymers</u>

Among the natural polymers suitable for practicing the present invention are the particularly preferred starches. Starch is a low-cost and abundant natural polymer composed of amylose and amylopectin. Amylose is essentially a linear polymer having a number average molecular weight in the range of 100,000-500,000, whereas amylopectin is a highly branched polymer having a number average molecular weight of up to several million. Unmodified, natural starches are obtained in granular form and may be derived from cereals or grains (such as corn, wheat, rice and sorghum), roots (such as cassava), legumes (such as peas), and tubers such as potato and canna. Such starch granules typically have a particle size less than about 50μm, which is the preferred particle size when practicing the granule embodiment. While less preferred, flours whose contents are predominately

starch, and which may also contain protein, oil and fiber, are operative in the present invention. While such other natural polymers are used for granular embodiment formulations, they will be processed so as to be in granular form and preferably will have a relatively uniform particle size of about 50 μm or less.

Starch granules for use in the granule embodiment will normally have a water content of less than about 15 wt.%, more preferably less than about 10 - 11 wt.%. As will be exemplified, granules may be pre-dried to less than about 1% moisture before compounding. Although preferred, pre-drying is not necessary.

Derivatized (modified) starches are also suitable for use in the present invention. "Derivatized starches" is meant to include starches which have been chemically treated so as to form starch esters, starch ethers, and cross-linked starches. "Modified" is meant that the starch can be derivatized or modified by typical processes known in the art (e.g. esterification, etherification, oxidation, acid hydrolysis, cross-linking and enzyme conversion). Typically, modified starches include esters, such as the acetate ester of dicarboxylic acids/anhydrides. Particularly useful are the alkenyl-succinic acids, anhydrides, ethers (such as the hydroxyethyl and hydroxypropyl starches), starches oxidized with hypochlorite, starches reacted with cross-linking agents such as phosphorus oxychloride, epichlorhydrin, hydrophobic cationic epoxides, and phosphate derivatives prepared by reaction with sodium or potassium orthophosphate or tripolyphosphate and

combinations thereof. These and other conventional modifications of starch are described in publications such as *Starch: Chemistry and Technology*, 2nd edition, editor Whistler et al., and *Starch Derivatives: Production and Uses*, Rutenberg et al., Academic Press, Inc. 1984.

For example, starch esters may be prepared using a wide variety of anhydrides, organic acids, acid chlorides, or other esterification reagents. Examples of anhydrides are acetic, propionic, butyric, and so forth. Further, the degree of esterification can vary as desired, such as from one to three per glucosidic unit of the starch, or as appropriate given the number of hydroxyl groups in the monomeric unit of the natural polymer, if selected to be other than starch. Similar or different esterified natural polymers, with varying degrees of esterification, can be blended together for practicing the present invention. Although esterified starches are stable to attack by amylases, in the environment the esterified starches are attached by microorganisms secreting esterases which hydrolyze the ester linkage.

Starch esters tend to be hydrophobic in contrast to starch raw materials (that is, derived by usual techniques from natural sources such as corn). Thus, depending upon the particular application, one may prefer to choose an hydrophobic starch ester rather than a hydrophilic starch in formulating compositions of the present invention.

Although starches are preferred for use as the natural polymers, particularly due to ready availability and low cost, but as earlier noted, other suitable natural polymers (in or prepared to be in granular form of a suitable particle size) are hydroxyl containing polymers such as cellulose, hemicellulose, chitin, guar gum, locust bean gum, pectin, xanthan, algin, agar, and dextran. Some of these can play the role of filler, also. Excellent results have been obtained with both granulated guar gum and cellulose powder.

Suitable Thermoplastic Polyesters

The composition includes a thermoplastic polyester. Among the thermoplastic polyesters, a poly(lactic acid)(PLA) is preferred. The PLA is prepared and used in a pelletized form. Examples of other suitable thermoplastic polyesters include polyhydroxy(butyrate-co-valerate)(PHBV), poly(butylene succinate adipate) and poly(butylene succinate) copolyesters such as Bionolle™ from Showa Denko, cellulose acetate, polycaprolactone, and copolyesters of aliphatic-aromatic copolymer of adipic and terephthalic acids with butanediol such as Eastar Bio Copolyester and poly(ethylene terphathalate)(PET) such as Biomax copolyesters from DuPont. It should be appreciated that these thermoplastic polyesters are conventional and known in the art.

The thermoplastic polyesters may be prepared with additives to increase the rate of crystallization. For example, an additive such as talc or boron nitride may be added to a

thermoplastic polyester such as poly(lactic acid)(PLA) to increase the rate of crystallization of the PLA. It should be appreciated that other suitable additives may be added to the thermoplastic polyester to increase the crystallization.

Other Components

A plasticizer can be added to the inventive compositions to achieve greater material processability and product flexibility, although plasticizers typically soften the compositions in which they are included. This is not always true, however, of compositions of the present invention, as will be discussed hereinafter. Molded articles prepared from blends including plasticizers preferably use plasticizers that are biodegradable. Examples of biodegradable plasticizers include various esters, such as phthalate esters and citric acid esters, and various other biodegradable esters known in the chemical arts.

Inorganic fillers can be added, such as talc, calcium carbonate, diatomaceous earth, and so forth.

Nucleating agents can be added, such as talc, boron nitride, and so forth.

Other optional components known in the art, including, but not limited to, external lubricants, anti-blocking agents, anti-static agents, slip agents, pro-heat stabilizers, antioxidants, pro-oxidant, and additives may be incorporated, depending upon the application.

Method of Making

A method, according to the present invention, is provided for making a polymer composition. In general, the method includes providing a first component being a hydroxy-functional polymer, providing a second component being a natural polymer such as starch and providing a third component being a thermoplastic polyester such as poly(lactic acid)(PLA). The method includes mixing these components in a single screw extruder, a twin screw extruder, a Banbury mixer, a roll mill or any intensive mixer at a temperature and for a time sufficient to provide an intimate, well-dispersed mixture of the components. Preferably, the components are brought together and combined by compounding in an appropriate melt extruder from which the blend is extruded in the form of strands or sheets. The strands or sheets are then pelletized and molded into articles by conventional processes such as injection molding.

The method may include the step of forming bars from the sheets. The method may include the step of heating the polymer composition or formed bars for a predetermined time period such as up to 60 minutes and at a predetermined temperature such as up to 120°C to increase high temperature stability. It should be appreciated that other additives or treatments may be used to impart high temperature stability of the formed bars. It should also be appreciated that such additives or heating causes an annealing of the polymer composition to increase high temperature stability thereof.

EXPERIMENTAL

Aspects of the present invention will now be illustrated, without intending any limitation, by the following examples. Unless otherwise indicated, all parts and percentages are by weight.

EXAMPLE 1

Compositions of the present invention were made by the method, according to the present invention. Granules of starch, in this example cornstarch, pellets of PHEE Adipic(Adipic) and pellets of poly(lactic acid)(PLA) were provided and admixed. The granules of starch were pre-dried to approximately 1 wt.% moisture. These components were hand mixed and compounded. This compounding was performed on a Brabender PL2000 torque rheometer using a mixing screw with a fluted dispersive mixing section and a notched distributive section. Temperatures during the compounding ranged from about 120°C to about 180°C. The resultant compositions were in the initial form of strands, which were then air cooled and pelletized. Specific compositions were chosen so that the final compounded pellets included as follows: Sample # 1 is 60 wt.% starch and 40 wt.% resin (PLA/Adipic), of which the 40 wt.% resin consisted of 90% PLA and 10% Adipic, for a ratio of 60/36/4 of starch/PLA/Adipic; Sample #2 is 60 wt.% starch and 40 wt.% resin (PLA/Adipic), of which the 40 wt.% resin consisted of 50% PLA and 50% Adipic, for a ratio of 60/20/20 of starch/PLA/Adipic; and Sample #3 is 60 wt.% starch and 40 wt.%

resin, of which the 40 wt.% resin consisted of 10% PLA and 90% Adipic, for a ratio of 60/4/36 of starch/PLA/Adipic. The pellets formed were re-fed to the Brabender PL2000 torque rheometer, but fitted with a slit die (3.54 cm x 0.5 mm) to form a thin sheet. The sheets were stamped to form tensile bars for subsequent physical testing. Sample #1 did not provide a smooth sheet and it was difficult to stamp out representative tensile bars. Sample #2 provided tensile bars that had a tensile strength of 17.6 MPa and Sample #3 provided tensile bars that had a tensile strength of 30.4 MPa.

EXAMPLE 2

Compositions of the present invention were made using cornstarch, PLA and Adipic. Starch/Adipic (60/40) pellets were prepared and processed on a ZSK 30 Twin Screw Extruder. Moisture content of the starch was 4% to provide 60/40 pellets with a moisture content of approximately 2.4%. Samples of the composition were prepared by blending into the starch/Adipic (60/40) pellets various levels of the PLA pellets. The PLA pellets were added to make five different compositions which were compounded on the Brabender PL2000 torque rheometer of Example 1. Pellets were formed as in Example 1 and re-fed to the Brabender as in Example 1. The extrudates of the various compositions were thin sheets that were stamped to provide tensile bars for subsequent physical testing. Several properties of the various compositions tested are summarized in Table A.

Table A

Sample No. 16191-2	Mass 60/40	PLA added	%PLA(tot)	%Starch	%Adipic
1	96	4	4	57.6	38.4
2	92	8	8	55.2	36.8
3	88	12	12	52.8	35.2
4	84	16	16	50.4	33.6
5	80	20	20	48	32

Adipic/PLA	%PLA	Tensile Strength(MPa)
9.6	9.4	31
4.6	17.9	25
2.9	25.4	21
2.1	32.3	25
1.6	38.5	29

EXAMPLE 3

Formulations of starch and resin were prepared into several compositions as in Example 1. These compositions contain 50 wt.% starch and 50 wt.% resin. The 50 wt.% resin consisted of 15 wt. % Adipic and 35 wt.% PLA; 20 wt.% Adipic and 30 wt.% PLA; and 25 wt.% Adipic and 25 wt.% PLA. The formulations were hand mixed and compounded on the Brabender PL2000 torque rheometer as previously described in Example 1. Thin sheets were obtained as in Example 1 for stamping out tensile bars. After allowing the tensile bars

to remain for 7 days at 50% RH and 23°C, tensile strength properties were determined and summarized in Table B.

Table B

Sample	Starch%	Adipic%	PLA%	Tensile(MPa)
1	50	15	35	27
2	50	20	30	28
3	50	25	25	33

EXAMPLE 4

Dynamic mechanical analysis (DMA) was used to determine changes in the processed strands of composition of Example 3 after a particular heating period. A temperature of 120°C was selected and strands of composition were removed from an oven at zero minutes, 10 minutes, 20 minutes, 30 minutes, 40 minutes and 60 minutes. These heated strands were used for DMA. Samples of the strands showed that changes occurred rapidly with time as probe positions showed less and less movement with heating. At the annealing temperature for 40 and 60 minutes, there was little probe movement as the DMA temperature neared the PLA melting temperature of 150°C.

EXAMPLE 5

Additional compositions of 60 wt.% starch were made as in Example 1. Starch was dried to approximately 1% moisture and hand mixed with various levels of Adipic and PLA as in Example

1. Samples were processed on the Brabender and thin sheets were formed as in Example 1. The thin sheets were stamped into tensile bars and tensile strength properties were obtained. The properties are summarized in Table C.

Table C

Sample	Starch	%wt	Adipic	%wt	PLA	%wt	Tensile(MPa)
1	180g	60	24g	8	96g	32	14
2	180g	60	36g	12	84g	28	17
3	180g	60	48g	16	72g	24	21

EXAMPLE 6

Samples of the composition were prepared from starch, Adipic and PLA as in Example 1. The samples were hand mixed and compounded on the Brabender as in Example 1. The compounded samples were pelletized and used for injection molding on a Cincinnati Milacron 75T to form molded tensile bars. Tensile properties were obtained and summarized in Table D.

Table D

Sample	Starch	Adipic	PLA	Tensile(MPa)
1	908g	363g	545g	38.6
2	1090g	291g	436g	34.1

EXAMPLE 7

Several samples of the composition were prepared with starch at a level of 40 wt.%, 50 wt.%, 55 wt.%, 60 wt.%, 65 wt.% and 70 wt.% and various levels of Adipic and PLA as in Example 1. The samples were hand mixed, compounded on the Brabender and pelletized as in Example 1. The pellets were used for injection molding on the Cincinnati Milacron 75T to form molded tensile bars as in Example 6. Tensile strength properties were obtained and summarized in Table E.

Table E

Sample	Starch%	Adipic%	PLA%	Tensile(MPa)
1	40	26.7	33.3	39
2	50	15	35	28
3	50	10	40	28
4	55	11	34	28
5	60	12	28	32
6	65	10.5	24.5	-
7	70	9	21	-

EXAMPLE 8

A composition of starch 50 wt.%, Adipic 20 wt.% and 30 wt.% PLA was prepared and hand mixed. Sufficient boron nitride may be added into the hand mixed composition to increase the rate of crystallization of PLA and to be approximately 1 wt.% of the PLA added. The composition was compounded on the Brabender and

pelletized as in Example 1. The pellets were used for injection molding on the Cincinnati Milacron 75T to form molded tensile bars as in Example 6. Tensile properties of the tensile bars were 29MPa.

EXAMPLE 9

Attenuated Total Reflectance by FTIR data was obtained for the samples in the Example 7. The spectra were compared to spectra of PLA and Adipic. The surfaces of the tensile bars consisted mostly of PLA. Also, partial spectra of Adipic could be seen.

EXAMPLE 10

Two compositions were prepared, one with starch 49.5 wt.%, Adipic 19.8 wt.% and PLA 29.7 wt.%, and the other with starch 59.4 wt.%, Adipic 15.8 wt.% and PLA 23.8 wt.%. To each composition was added WaxOP of 1 wt.% as an external lubricant to assist in compounding and injection molding. The compositions were hand mixed and then compounded on a Leistritz Extruder. Strands produced from the Leistritz were pelletized. The pellets were used for injection molding on a Cincinnati Milacron 75T to form molded tensile bars as in Example 6. For injection molding, a mold temperature of either 205°F or 150°F was selected. Mold hold times were selected as 20 seconds or 60 seconds. Tensile bars were molded, collected, and stored at 50% RH and 23°C. Another two compositions were prepared, one with starch 63.7

wt.%, Adipic 13.7 wt.% and PLA 20.67 wt.%, and the other with starch 68.6 wt.%, Adipic 11.8 wt.% and PLA 17.6 wt.%. To each composition was added WaxOP of 2 wt.% as an external lubricant to assist in compounding and injection molding. The compositions were hand mixed and then compounded with a Leistritz Extruder. Strands from Leistritz were pelletized. The pellets were used for injection molding on a Cincinnati Milacron 75T to form molded tensile bars as in Example 6. For injection molding, a mold temperature of 210°F was selected for the 63.7 wt.% starch composition and 217°F was selected for the 68.6 wt.% starch composition. The tensile strength properties are summarized in Table F.

Table F

Sample	Starch	Adipic	PLA	Mold Temp	Mold Time (Sec)	Tensile (MPa)
1	49.5	19.8	29.7	205	20	34
2				205	60	31
3				150	20	33
4				150	60	35
5	59.4	15.8	23.8	205	20	34
6				205	60	37
7				150	20	40
8				150	60	33
9*	54.5	14.5	30.1	150	20	39
10	63.7	13.7	20.6	210	20	37
11				210	60	34
12	68.6	11.8	17.6	217	20	33
13				217	60	38

*Sample 9 was prepared by taking 100g of pellets from the 60 wt.% starch composition and blending into it 10g of PLA. The blended sample was fed into the Cincinnati Milacron 75T to form molded tensile bars.

EXAMPLE 11

Tensile bars from samples in Example 10 were selected for heating trials. Tensile bars containing 49.5 wt.% starch, 63.7 wt.% starch and 68.6 wt.% starch were heated at 100°C in an oven for 30, 15, 10, 5, 2.5 or 0 minutes. The heated tensile bars, after a brief cooling, were placed in a 2000ml beaker filled to approximately 1500ml with water heated to 90°C on a heating plate. Water was kept at 98°C to 100°C during the heating trials. Tensile bars were immersed in the heated water at about a 45 degree angle so that one could observe any bending of the tensile bars with time in the heated water. All tensile bars that were not heated in the oven, zero time, rapidly bent in a few seconds. Tensile bars heated for 2.5 minutes also bent within several seconds. All of the other tensile bars heated in the oven for 5, 10, 15 or 30 minutes retained their shape for one hour in the heated water. Upon removal from the heated water, the zero time and 2.5 minute time gave tensile bars that were bent while the other tensile bars retained their shape.

EXAMPLE 12

Dry starch has been found useful in compositions of the present invention. The compositions were prepared using two types of starch, one normal cornstarch (Buffalo 3401, Formula I) and a 3:1 blend of potato and rice starches (Formula II). The starches were pre-dried to less than 1% moisture content and then compounded in a Werner Psleiderer ZSK-30 Twin Screw Extruder with

Adipic at a 60/40 ratio. Strands from the extruder were pelletized. The pellets were mixed with PLA to give a final ratio of 40/27/33 starch/Adipic/PLA and passed through a Brabender 19mm Single Screw Extruder using a fluted mixing screw at 160°C. Resulting pellets were injection molded to form molded tensile bars on a Cincinnati Milacron injection molder. Formula I had a tensile strength of 43 MPa, elongation of 4.3% and Young's Modulus of 1.4 GPa. Formula II had a tensile strength of 45 MPa, elongation of 4.1% and a Young's Modulus of 1.5 Gpa.

EXAMPLE 13

Compositions were prepared using the steps previously outlined in Example 1. The compositions made consisted of 60 wt.% starch and 40 wt.% Adipic/polyhydroxy(butyrate-co-valerate)(PHBV). Resin blends of Adipic and PHBV were then compounded on the Brabender as in Example 1. Resin ratios varied from 90/10, 50/50 and 10/90. Pellets of the combined resins were blended with starch and compounded on the Brabender. Strands from the Brabender were pelletized. The pellets were re-fed to the Brabender fitted with a slit die. Thin slit films were collected and stamped to form tensile bars. Tensile strengths were 12.3 MPa for the 50/50 resin composition and 26.3 MPa for the 90/10 Adipic PHBV.

EXAMPLE 14

Compositions were prepared using Adipic polyester. The Adipic polyester was hand mixed with equivalent amounts of other additional resins. The mixed 50/50 samples were Adipic/Bionolle™, Adipic/Eastman cellulose acetate, and Adipic/polycaprolactone. Each of these mixtures were blended with starch to give three compositions of starch 60 wt.% and mixed resins 40 wt.%. These compositions were compounded on the Brabender fitted with a slit die. Tensile bars were stamped from the thin films from the die for physical properties. Tensile strengths were 11.8 MPa for the Bionolle™, 8.4 MPa for the cellulose acetate and 12.5 MPa for the polycaprolactone blends.

EXAMPLE 15

Composition of the present invention were prepared with the following method of this invention. Compositions were prepared using higher levels of starch in a range of 59 wt.% to 74 wt.% of the final composition. Adipic polyester was varied from 1 wt.% of the final composition to levels of 26.6 wt.% of the final composition. PLA levels varied from 13.3 wt.% to 39 wt.% of the final composition. The Adipic and PLA were hand-mixed and fed at the first section of a ZSK-30 Twin Screw Extruder. WaxOP at a 1 wt.% of the final composition was hand-mixed with starch which was pre-dried to about 1 wt.% moisture. Starch was fed at the sixth barrel of the ZSK-30 Twin Screw Extruder. Compounded strands from the ZSK-30 Twin Screw Extruder were pelletized.

Resulting pellets were injection molded to form molded tensile bars on a Cincinnati Milacron 75T injection molder. The physical properties are summarized in Table G.

TABLE G

Starch/PLA/Adipic

Sample #	Percent Starch	Percent Adipic	Percent PLA	Percent Wax OP	Modulus (MPa)	Percent Elongation	Tensile Strength (MPa) 1 Day	Tensile Strength (MPa) 8 Day	Tensile Strength (MPa) 28 Day
16374-49-01	0	0	100	0	914	11.3	67	82	66
16374-49-07	19	0	80	1	1317	7.5	58	57	62
16374-49-08	39	0	60	1	1200	5.7	47	59	45
16374-49-09	59	0	40	1	1494	3.9	42	41	36
16374-49-11	19	26.6	53.3	1	1316	5.9	55	54	57
16374-50-20	35.25	12.8	51	0.9	1511	4	47	48	59
16374-49-17	39	30	30	1	1390	5.4	51	50	57
16374-49-12	39	20	40	1	1365	4.9	52	50	47
16374-50-22	49	33.3	16.6	1	1615	4	49	47	57
16374-49-15	49	25	25	1	1234	6.3	49	47	43
16374-49-19	49	10	40	1	1356	4.3	42	49	45
16374-50-21	59	26.6	13.3	1	1506	4.3	46	45	44
16374-49-16	59	20	20	1	1514	5	47	45	46
16191-68 / 16374-49-13	59	13.3	26.6	1	1304	5.3	43	43	38
16191-84	59	10	30	1	1524	4.3	44	45*	54**
16191-84	59	8	32	1	1619	3.8	43	42*	52**
16374-49-18					1436	4.5	44		
16191-89	59	6.7	33.3	1	1377	5.0	44	43	37
16191-89	59	5.7	34.3	1	1479	4.6	45.0	40	39
16191-89	59	5	35	1	1457	4.7	40	43	36
16191-95b	59	3	37	1	1409	4.2	42	51	40
16191-95a	59	1	39	1	1389	4.0	41	47	35
16191-75 / 16374-50-28	64	11.7	23.3	1	1371	4.7	46	46	41
16191-75 / 16374-49-14	69	10	20	1	1565	3.8	42	43	37
16191-84	69	7.5	22.5	1	1755	3.4	38	34*	39**
16191-84 / 16374-50-30	69	6	24	1	1662	3.7	40	37*	43**
16562-1a	69	1	29	1	1504	4.0	41	36	20

16191-75 / 16374-50-29	74	8.3	16.6	1	1643	3.5	36	40	35
16562-1e	74	5	20	1	1715	3.5	42	34	29
16562-1d	74	3	22	1	1688	3.9	40	36	37
16562-1c	74	1	24	1	1639	4	47	43	37
16562-2a(2.2%MC)	59	8	32	1	1428	4.45	45	41	30
16562-2b(5.2%MC)	59	8	32	1	1386	4.36	43	37	33.3
16562-2c(11%MC)	59	8	32	1	1316	4.11	36	35	29.3
16374-50-23	39	40	20	1	1126	4.25	45	41	40
16374-50-24	15.6	66.66	16.66	1	1202	4.52	39	43	31
16374-50-25	27.57	57.1	14.29	1	1201	4.95	41	42	33
16374-50-26	43.44	44.44	11.11	1	1068	6.36	47	44	39
16374-50-31	69	24	6	1	1550	4.44	46	45	40
16374-50-27	60.54	30.77	7.69	1	1364	4.82	48	48	43
16374-49-2	0	33.33	66.66	0	978	12.33	66	49	56
16374-49-3	0	20	80	0	1072	9.71	64	53	55
16374-49-4	0	50	50	0	990	12.35	60	41	32
16374-49-5	0	66.66	33.33	0	915	7.69	49	47	30
16374-49-6	0	80	20	0	940	5.33	38	30	28

EXAMPLE 16

Compositions were prepared, one with starch 49.5 wt.%, Adipic 19.8 wt.% and PLA 29.7 wt.%, and the other with starch 59.4 wt.%, Adipic 15.8 wt.% and PLA 23.8 wt.%. To some of the compositions was added WaxOP of up to approximately 1 wt.% as an external lubricant to assist in compounding and injection molding. The 16323-86 Series compositions were hand mixed and then compounded twice on the Brabender and pelletized as in Example 1. The 16191 Compositions were compounded in a ZSK-30 Twin Screw Extruder as shown in Example 15. A plasticizer was added at the eighth heating zone of the barrel of the extruder after Adipic-PLA resin blend in the feed barrel and starch in the sixth heating zone of the barrel. Two types of plasticizers were used, one Citric Acid Ester (A2) in a weight % of approximately 1 to 4 wt.% and Citric Acid Ester (A4) in a weight % from

approximately 2 to 20 wt.%. The esters are fully substituted citric acid derivatives. The pellets were used for injection molding on a Cincinnati Milacron 75T to form molded tensile bars as in Example 6. The tensile properties are summarized in Table H.

TABLE H

Starch/Adipic/PLA w/Plasticizer

Sample Number	Starch	Resin 1 Adipic/ 2 PLA	Wax OP	Plasticizer A2	Plasticizer A4	Young's Modulus (MPa)	Percent Elongation	Tensile Strength (MPa)
16191-67	60	40	0	0	0	1304	5.3	43
16191-70	58.28	39.51	0.99	1.23	0	1573	3.5	44
16191-71	58.28	39.51	0.99	0	1.23	1573	3.5	44
16191-72	57.79	39.18	0.98	2.1	0	1393	3.1	35
16191-73	57.79	39.18	0.98	0	2.1	1330	4.7	35
16191-74	57.28	38.83	0.97	3	0	1508	2.6	30
16191-75	57.28	38.83	0.97	0	3	1392	3.0	32
16191-77	56.73	38.46	0.96	4	0	1213	4.3	35
16191-77	56.73	38.46	0.96	0	4	1157	5.4	30
16323.86*	60	35	0	0	5	795	5.4	18
16323-86	60	30	0	0	10	114	64.1	4
16323-86*	60	25	0	0	15	111	13.9	3
16323.86*	60	20	0	0	20	91	14.6	2

*Sample 16323-86 Series had a 3/2 ratio of PLA/Adipic and compounded on Brabender, 2 passes through.

EXAMPLE 17

Compositions of the present invention were prepared using the steps outlined in Example 15. The compositions were prepared using starch in a range of 57 wt.% to 59 wt.% and Adipic in a range from 5 wt.% to 13 wt.% and PLA in a range of 26 wt.% to 35 wt.%. To each composition was added Talc such as Microtalc 609

in a range of 0.25 wt.% to 2.0 wt.% to enhance crystallinity of PLA. Also, to each composition was added WaxOP of 1 wt.% as an external lubricant to assist in compounding and injection molding. The starches were pre-dried to less than 1% moisture content and blended with the Talc and WaxOP then compounded in a ZSK-30 Twin Screw Extruder with Adipic/PLA blends. Strands from the extruder were pelletized. Resulting pellets were injection molded to form molded tensile bars on a Cincinnati Milacron 75T injection molder. The physical properties are summarized in Table I.

TABLE I

Starch/PLA/Adipic w/Talc

						Physical Properties				
Sample #	Percent Starch	Percent Adipic	Percent PLA	Percent Wax OP	Percent Talc	Modulus (MPa)	Percent Elongation	Tensile Strength (MPa)		
								1 Day	8 Day	28 Day
16191-74	58.75	13	26	1	0.25	1556	3.6	43	41	41
16191-74	58.50	13	26	1	0.50	1523	4.3	49	48	43
16191-74	58	13	26	1	1	1473	4.1	46	48	43
16191-83	57.75	13	26	1	1.25	1541	4.4	46	45	58
16191-83	57.50	13	26	1	1.50	1593	4.1	45	44	51
16191-83	57	13	26	1	2	1616	4.7	45	45	60
16191-90	58	5	35	1	1	1362	5.2	44	41	37

EXAMPLE 18

Starches with various levels of moisture content have been found useful in compositions of the present invention. The compositions were prepared using starches at 59 wt.% having from

0.5 wt.% to 11.1 wt.% starting moisture content (H_2O) and then compounded in a ZSK-30 Twin Screw Extruder with Adipic PLA blends. To each composition was added WaxOP of 1 wt.% as an external lubricant to assist in compounding and injection molding. The PLA and Adipic were mixed prior to reaction with starch and fed at the feed throat of the ZSK-30 Twin Screw Extruder. Strands from the ZSK-30 Twin Screw Extruder were pelletized. The pellets had a moisture content in a range of 1.5 wt.% to 1.8 wt.%. The pellets were injection molded to form molded tensile bars on a Cincinnati Milacron 75T injection molder. The physical properties are summarized in Table J.

TABLE J

Starch/PLA/Adipic

Sample #	Percent Starch	Moisture Starting	Content Pellets	Percent Adipic	Percent PLA	Physical Properties Modulus (MPa)	Percent Elongation	Tensile Strength (MPa) 1 Day	8 Day	28 Day
16191-84	59	0.5		8	32	1619	3.8	43	42	52
16562-2a	59	2.2	1.5	8	32	1428	4.5	45	41	30
16562-2b	59	5.2	1.6	8	32	1386	4.4	43	37	33
16652-2c	59	11.1	1.8	8	32	1316	4.1	36	35	29

Extrudates were pelletized and H_2O levels of 1.5, 1.6 and 1.8 were determined.

EXAMPLE 19

Compositions of the present invention were prepared using a copolyester in place of PLA. The copolyester is known as Eastar 14766 which is commercially available from Eastman Chemical Company. The compositions were prepared with Adipic of

1 wt.% and without Adipic. The starches were pre-dried to less than 1% moisture content and then compounded in a ZSK-30 Twin Screw Extruder at ratios of 60/40 starch/copolyester or 60/39/1 starch/copolyester/adipic. Strands from the extruder were pelletized. Resulting pellets were injection molded to form molded tensile bars on a Cincinnati Milacron 75T injection molder. The physical properties are summarized in Table K.

TABLE K

formula	starch	Eastar	PHEE	TS (MPa)	Elongation	Toughness
1	60	40	0	6.4	66	2.72
2	60	39	1	10.7	49	4.22

EXAMPLE 20

Compositions were prepared using cyclohexanedicarboxylic (CHD) acid which is a poly (hydroxy ester ether) (PHEE) available from the Dow Chemical Company, Midland, Michigan in place of Adipic. The compositions were prepared using two types of starch, one starch at 59 wt.% and another starch at 69 wt.%. To each composition was added WaxOP of 1 wt.% as an external lubricant to assist in compounding and injection molding. The starches were pre-dried to less than 1% moisture content and then compounded in a ZSK-30 Twin Screw Extruder with CHD from 1 wt.% to 3 wt.%. CHD was hand-mixed with PLA to provide the resin blend and added in the feed throat of the ZSK-30 Twin Screw Extruder, prior to mixing with starch. Strands from the extruder were pelletized. Resulting pellets were injection molded to form

molded tensile bars on a Cincinnati Milacron 75T injection molder. The physical properties are summarized in Table M.

TABLE M

Starch/PLA/CHD

Sample #	Percent Starch	Percent CHD	Percent PLA	Percent Wax OP	Modulus (Mpa)	Percent Elongation	Tensile Strength MPa		
							1 Day	8 Day	28 Day
16562-12-1	59	1	39	1	1286	5.3	47	44	42
16562-13-1	59	3	37	1	1345	5.7	51	46	42
16562-12-2	69	1	29	1	1412	4.8	45	43	37
16562-13-2	69	3	27	1	1501	4.8	51	44	41

(Physical Properties)

EXAMPLE 21

The Cincinnati Milacron 75T injection molder was fitted with a pencil cup mold. Compositions were prepared using the steps outlined in Example 15. The compositions were prepared using four types of compositions from Table G in Example 15 to make pencil cups. The compositions were as follows: starch 59 wt.%/Adipic 13.3 wt.%/PLA 26.7 wt.%/WaxOP 1 wt.% (Sample #14 in Table G); starch 59 wt.%/Adipic 8 wt.%/PLA 32 wt.%/WaxOP 1 wt.% (Sample #16 in Table G); starch 64 wt.%/Adipic 11.7 wt.%/PLA 23.3 wt.%/WaxOP 1 wt.% (Sample #23 in Table G); and starch 69 wt.%/Adipic 3 wt.%/PLA 27 wt.%/WaxOP 1 wt.%. Excellent pencil cups were formed.

EXAMPLE 22

Two formulations were compounded on a ZSK-30 Twin Screw Extruder and chopped into pellets. The formulations were: 59/13/27/1 starch/PHEE/PLA/WaxOP and 65/1/32/2 starch/PHEE/PLA/WaxOp. The pellets were subsequently fed into a Cincinnati Milacron injection molding machine with a three-cavity mold for making cutlery articles (knife, fork, and spoon). Water was heated in a beaker to 75 °C and cutlery articles molded for these formulations were placed in the water to test the dimensional stability at elevated temperatures. Articles of the first formulation (59/13/27/1) began to bend in a few seconds, while articles of the second formulation (65/1/32/2) did not bend after two minutes exposure to the hot water.

The present invention has been described in an illustrative manner. It is to be understood that the terminology used is intended to be in the nature of words of description rather than of limitation and the examples are intended to illustrate and not limit the scope of the present invention. Therefore, within the scope of the appended claims, the present invention may be practiced other than as specifically described.